<u>ATTACHMENT F</u>

OVERVIEW OF COASTAL HYDRAULICS

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OVERVIEW OF COASTAL HYDRAULICS

1.0 INTRODUCTION

Coastal hydraulics analysis performed during the Mid-Bay Island Feasibility Study were focused in two areas: hydrodynamic and sedimentation analyses for use in evaluating the environmental impacts of alternative island alignments; and a life cycle analysis for design of stone protection structures at James and Barren Island. This attachment provides an overview of the coastal hydraulics analyses accomplished in the Feasibility Study.

2.0 PRELIMINARY HYDRODYNAMIC AND SEDIMENTATION ANALYSIS

Hydrodynamic and sediment transport modeling in the vicinity of James and Barren Islands was performed by Moffet Nichols to determine the effect of alternative island alignments on water levels, current velocities, and sedimentation and accretion of the bay bottom surrounding the islands. The purpose of this analysis was to identify potential impacts of the alternative alignments on water quality and environmental resources including oyster bars and submerged aquatic vegetation. The analysis was also used to make judgments on the effect of the proposed project on reducing erosion of the existing James and Barren islands and providing sheltering to the mainland shorelines of Taylors and Hoopers Islands. The detailed hydrodynamic and sedimentation reports are provided in Attachment G - *James Island Hydrodynamics and Sedimentation Modeling* and Attachment H - *Barren Island Hydrodynamics and Sedimentation Modeling*.

The models used for the analysis included RMA-2, a depth-averaged, two dimensional finite element hydrodynamic flow model for simulation of velocities and water surface elevations, and SED-2D, a sediment transport model for cohesive and non-cohesive sediment. The models were applied for a 2 week period in 2001 representative of typical predicted astronomical tide conditions at James and Barren islands (ie. normal, spring, and neap tides). The sediment transport model was applied separately for cohesive sediments (grain size of 0.1mm) and non-cohesive sediments for wind conditions of 0, 4-, 13-, and 16-mph for all 16 principal compass directions. Modeled non-cohesive sediment transport was negligible for 4- and 13-mph winds, but significant for 16-mph winds in the NNW, SSE, WNW(at James) and W(at Barren) directions. Modeled cohesive sediment transport was negligible for 4 mph winds, but significant for 13- and 16- mph winds.

The results of the hydrodynamic analysis indicate that there will be no impacts on the local tidal elevations for any of the alternatives at James and Barren Island. Flow is expected to be displaced northward and southward, generally resulting in an increase in local current velocities north and south of the proposed alternatives at James and Barren Island. Local current velocities are generally found to be reduced east of the existing James and Barren islands. There is an increase in the ebb and flood current velocities between alternative alignments and the southernmost existing remnant island at James Island. An increase in the flood current velocity occurs between the alternative alignments and the northern end of the existing remnant island at

Barren Island. Peak ebb and flood currents in the main bay are not predicted to change with any of the alternatives. Overall, the results of the modeling did not shown any major differences in the impacts of the alternative island configurations at James and Barren Islands on hydrodynamics and sedimentation.

3.0 LIFE CYCLE ANALYSIS

Methods used in the analysis of coastal processes and design of coastal structures in the Chesapeake Bay have undergone significant evolution in recent years. First, recent advances in numerical modeling technology have produced tools that significantly improve the accuracy of wave and water level estimates. Previous methods used in the design of coastal structures in the Chesapeake Bay applied traditional approaches that assumed the coincidence of extreme waves and water levels for a single storm and point in time. This assumption is not always realistic and can result in overly conservative designs. These new technologies allow for the hindcast of time series of winds, waves, and water levels for historical storms based upon historical information. Secondly, the traditional approaches do not account for key life-cycle processes that account for progressive damage due to a series of successive storms that may occur between maintenance cycles over the life of the structure. Thirdly, these approaches do not lend themselves to a clear analysis of the trade off between initial construction and maintenance costs over the life of the project. Lastly, the traditional approaches are based solely on historical storms and do not take into account the natural variability of future storm conditions.

Because of the limitations of traditional tools and the emergence of improved technologies, the Baltimore District requested the Engineer Research and Development Center, Coastal and Hydraulics Laboratory (CHL) to apply state-of-the-art tools and updated methodologies for evaluation of coastal processes and analysis of the life-cycle cost of stone protection for the James and Barren Island projects. A detailed description of the life-cycle analysis for James and Barren Island is provided in Attachment I – *Life-Cycle Analysis of Mid Bay and Poplar Island Projects*.

The approach applied for the life cycle analysis consisted of the following:

a. Identify historical tropical and extratropical storms needed to develop design conditions at James and Barren Islands.

b. Acquire wind fields for historical storms identified in *a*, to be used for water level modeling. Open-ocean winds for most storms were available from previous studies.

c. Adjust wind fields over Chesapeake Bay waters as needed to represent winds over the bay suitable for water level modeling.

d. Analyze existing historical data from regional anemometers in order to develop local winds over Chesapeake Bay fetches for wave analysis

e. Compute historical storm water levels using the existing ADCIRC numerical model, updating the regional bathymetry and shoreline grid already developed for other NAB studies at Ocean City Inlet and Assateague Island.

f. Hindcast historical storm waves using model winds along with measured winds from several area anemometers. Compute historical offshore waves using relationships for wind-wave growth over irregular, restricted fetches.

g. Transform waves through shallow nearshore waters to shore using a spectral wave transformation model (STWAVE).

h. Compute responses for these historical events, such as run-up, overtopping as a function of crest height, structure damage as a function of stone size, and required toe stone weight. Use techniques based on recommendations given in the CEM.

i. Recreate multiple life cycles of storms and project responses using the EST. Each life cycle represents a possible future condition, which is statistically consistent with historical storm forcing, response, and sequencing information. The EST simulation includes progressive revetment damage due to successive storms that may occur between maintenance opportunities. Realistic maintenance cycles are incorporated into the simulation.

j. Compute life-cycle damage and function for selected designs that appear to be favorable.

3.1 Selection of Historical Tropical and Extratropical Storms. A total of 95 historical tropical (hurricanes) and extratropical (northeasters) storms were selected to use in simulations of water levels and waves in the Chesapeake Bay. Fifty-two hurricanes that traversed the Bay were selected from the North Atlantic Hurricane Track Database (1851-2003) based upon the following criteria: maximum wind speeds greater than 50 knots in the area between 75 and 79 deg W longitude and 36 and 29 deg N latitude. Forty-three northeasters were selected from the reanalysis project database (Swail et al. 2000) by the Atmospheric Environmental Service of Canada (AES-40) and the National Center for Atmospheric Research (NCAR). Northeasters were selected based upon the following criteria: peak wind speeds greater than 20 m/s (66 ft/s) or 10 m/s (33 ft/s) with durations exceeding 3 days at the ocean entrance of the Chesapeake Bay. Adjustments were made to the wind fields to account for overland and overbay effects. The wind and pressure fields for each storm were then applied in a hydrodynamic model for Chesapeake Bay to attach the response of the bay to each storm. Chapter 2 of Attachment I provides a detailed description of the selection of tropical and extratropical storms.

3.2 Hydrodynamic Modeling. The hydrodynamic model ADCIRC (Kuettich et al. 1993) was applied to the Chesapeake Bay area for each of the 95 historical storm events to predict water levels at James and Barren Island for each event. A regional scale ADCIRC grid of the Chesapeake bay was developed using the National Ocean Service (NOS) Digital Navigation Charts (DNC) supplemented with other available sources of data, including more detailed data from recent bathymetric surveys in the project vicinity. The grid cells in the model range from minimum resolution of 50 m and a maximum cell size of 500 m in the open ocean.

NOAA historical water level data (1996-2003) for Chesapeake Bay was used to examine seasonal water level variations and to validate the hydrodynamic model. The validation process for hurricane simulation applying wind and pressure fields involved comparison of measured and predicted water levels at twelve NOAA stations for two major hurricanes, Fran (1996) and Isabel (2003), and four moderate hurricanes, Bertha(1996), Bonnie (1998), Earl (1998), and Floyd (1999). The model was similarly validated for two extratropical events. An average water level increase of 0.1 m (0.3 ft) was added to predicted water levels for events occurring during the March to November timeframe to account for seasonal variation. Predicted water levels for both tropical and extratropical events generally agree well with the measured water levels.

The validated model was then applied to the 52 hurricanes and 42 extratropical storms to compute water levels at James and Barren Islands. Time series and maximum water levels were extracted at 6 locations along Barren Island and 6 locations along James Island. Maximum water levels at James and Barren Island reached +5.6 ft msl during the 1933 hurricane, just slightly exceeding the water levels during Hurricane Isabel in 2003. Maximum water level for northeasters reached +3 ft msl. The predicted water levels for the 95 historical storms were used to estimate wave heights around each island and in the life-cycle simulations. A detailed description of the ADCIRC hydrodynamic modeling is provided in Chapter 3 of Attachment I.

3.3 Wave Modeling. Modeling of waves at James and Barren Islands involved several steps including validation and adjustment of wind inputs, generation of offshore wave parameters (height, period and direction), estimation of wave energy spectra from the wave parameters, and transformation of waves over the complex nearshore bathymetry at each site. Winds used for wave modeling were validated with open-water measurements at the NDBC Thomas Point station. The AES-40 winds were adjusted to compensate for reduced over-water drag. Offshore wave parameters were then generated using the narrow-fetch wave methodology (Smith 1991) in the Automated Coastal Engineering System (ACES). The narrow fetch wave growth methodology was calibrated/validated using wave measurements by NOS/NOAA during Hurricane Isabel.

The STWAVE model (Smith et al. 2001) was utilized to transform the offshore waves over the complex nearshore bathymetry at each site. STWAVE calculates the wave shoaling, refraction, sheltering, and breaking over the nearshore bathymetry to give the spatial distribution of wave height, period, and direction around each island. A TMA parametric spectral wave shape was applied to estimate wave spectra from the wave parameters. Several model grids were developed to allow for simulation of various directions of wave approach. The offshore wave spectra, along with the water levels, were input into the STWAVE model to compute local wave parameters around each island for each storm event. The resulting time history of local waves and water levels was archived at nearshore stations around each island for each of the selected storms for application in the life-cycle analysis. A detailed description of the wave modeling is provided in Chapter 4 of Attachment I.

3.4 Life-Cycle Simulation of Waves and Water Levels. A life-cycle analysis of the waves and water levels at James and Barren Islands was performed by ERDC to establish the range of conditions to which proposed structures would be subjected over the life of the projects. A 148-year time history of offshore wave and water levels associated with historical storm events was initially developed in the vicinity of James and Barren Islands. The available time history consists only of storms, since non-storm time periods are not a consideration for structure design. The time period covered by tropical storms (hurricanes) is 148 years (1856-2003), while the time period for extratropical storms (northeasters) is only 50 years (1954-2003). Since northeasters are more common than tropical storms and less likely to be as severe, the 50-year period of northeasters available in the hindcasts is considered to be representative of conditions over the 148 year time history. Therefore, the 50-year historical record of northeasters was folded back to populate the earlier years of the time history (1856 – 1956) with northeasters. The final 148-year time history consisted of 179 storm events. A future life-cycle scenario of wave and water levels will be developed at a later phase of design. A detailed description of the results of the life-cycle analysis of waves and water levels is provided in Chapter 5 of Attachment I.

3.5 James Island Stone Protection Optimization. A life-cycle analysis of the stone protection structures was performed to establish the optimum design features for the structure including crest elevation, armor stone size, and side slopes. The life-cycle analysis accounts for progressive damage due to a series of successive storms that may occur between maintenance cycles over the life of the structure. This approach was initially intended to be applied to establish optimum design features that balance initial cost with expected future maintenance in order to reduce the overall costs of the structure. However, due to significant concerns over the possible impacts of sediments that could be released if a large breach in the dike could not be repaired in a timely manner, a decision was made to design the stone protection to minimize the potential for large breaches and associated repairs.

The life-cycle analysis of potential breaches considered two modes of failure: damage to the crest due to overtopping and displacement of stone along the slope due to armor instability. The preliminary results of the overtopping analysis indicated that a structure at +10 ft mllw along the southern, western, and northern exposures, and +8 ft mllw along the eastern exposure, would have an insignificant risk of overtopping over the life of the project. The preliminary results of the armor stability analysis indicate that armor and toe stone sized for a 50-year return interval would have an insignificant risk of a breach due to armor instability over the life of the project. The preliminary stone size recommended for the northerly, westerly, and southerly exposures is 2500lbs for armor stone and 3500 lbs for toe stone. The preliminary stone size recommended for the easterly exposures is 250lbs for armor stone and 1000 lbs for toe stone. A side slope of 1:3 was considered to be optimum from a geotechnical perspective. A detailed description of the results of the life-cycle analysis of stone protection is provided in Chapter 8 of Attachment I for James Island and Chapter 9 of Attachment I for Barren Island.

3.5 Barren Island Stone Protection Optimization. Stone protection structures for Barren Island would consist of several components: raising the existing stone sill along the northern portion of the existing island's westerly shoreline, a new nearshore sill along the southern portion of the existing westerly shoreline, a continuous breakwater extending south along the sand spit remnants of the historical island footprint, and possibly a new sill or breakwater along the existing northerly shoreline. A life-cycle analysis of the stone protection structures for Barren Island was applied to optimize design features for the project including crest elevation, armor stone size, and side slopes. Both structural stability and functional performance of the breakwater/sill were considered. The functional performance of the stone protection structures were evaluated in terms of their ability to achieve the project's stated purposes: to protect the nearshore habitat along the existing shoreline at Barren Island, to provide protection to the submerged aquatic vegetation (SAV) areas on the east side of the island, and to create wetlands using maintenance dredged material from local channels.

An overtopping analysis was performed to establish the optimum crest elevations for the nearshore sill and breakwater structures. Crest heights of +2-, 4-, 6-, and 8-feet mllw were evaluated. The continuous stone breakwater was evaluated in terms of its ability to reduce wave heights to levels tolerable by SAV. Available literature on SAV indicates that the tolerable wave height for SAV ranges from 0-2 meters with an average of 1 meter. The preliminary results for the overtopping analysis indicate that a crest height of +4 ft mllw would provide SAV protection to the limiting tolerable wave height of 1 m for just over a 30-year return period storm event. A structure of +6 ft mllw would reduce waves to tolerable levels for SAV for up to a 50-year return period event. These preliminary results are based solely on an overtopping analysis, which is considered to be the predominant factor affecting the transmitted wave for submerged structures. Future design efforts will also need to consider wave transmission through the structure and any gaps in proposed segmented structures, diffraction through the gap between the mainland and the proposed alignment, and local waves generated on the eastern side of the project.

The results of the overtopping analysis were considered along with other factors to establish the recommended crest heights for the sill and breakwater structures. For the nearshore Barren Island sill structures, a crest height of +4 feet mllw was determined to be desirable to achieve the project purpose of protecting the nearshore habitat along the existing island shoreline from erosion and for creation of wetland areas. During normal conditions and less extreme storm events, a sill at +4 ft mllw would provide wave protection for nearshore habitat and wetland areas planted behind the structure. During moderate and extreme storm events when water levels exceed +4 mllw, however, low lying wetland areas behind the sills would be submerged. Established wetland areas typically experience insignificant levels of erosion during submerged conditions and actually provide some additional attenuation of wave energy acting on the island shoreline due to the frictional resistance of the plant stems. It is expected that during moderate to extreme storm conditions, the mid to upland portions of the existing island may experience some erosion. Erosion of the upland portions of the island during moderate and extreme storm events was considered to be acceptable since it is a natural process that would be difficult to prevent without completely armoring the shoreline. For the continuous breakwater structure, a crest height of +6 mllw was selected based upon guidance from the Coast Guard regarding navigation safety. Since the continuous stone breakwater would essentially be located in open water, the structure needed to be built high enough to be visible to boaters during higher water conditions. A crest height of +6 feet would also protect SAV plants from damage due to wave heights associated with storms up to 50-year return period.

The preliminary results of the armor stability analysis indicate that armor and toe stone sized for a 50-year return interval would be stable over the life of the project. The preliminary armor stone size recommended was 1300 lbs for the stone sill along the northern portion of the westerly alignment and 1000 lbs for the breakwater along the southern portion of the westerly alignment. However, due to uncertainty in the water depths along the sand spit which could affect wave heights, it was decided to use a conservative 1300 lb armor stone for the entire project. A side slope of 1:1.5 was considered to be optimum. A detailed description of the results of the life-cycle analysis of stone protection at Barren Island is provided in Chapter 9 of Attachment I.

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